AD

TECHNICAL REPORT ARCCB-TR-95001

A SIMPLE AND ACCURATE TECHNIQUE FOR MONITORING CRACK GROWTH BEHAVIOR USING A WAVE FORM ANALYZER

D. ERIC LEIGHTON
RONALD T. ABBOTT

JANUARY 1995

US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
BENÉT LABORATORIES
WATERVLIET, N.Y. 12189-4050

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade name(s) and/or manufacturer(s) does not constitute an official indorsement or approval.

DESTRUCTION NOTICE

For classified documents, follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.

For unclassified, unlimited documents, destroy when the report is no longer needed. Do not return it to the originator.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
January 1995

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
A SIMPLE AND ACCURATE TECHNIQUE FOR MONITORING CRACK GROWTH BEHAVIOR USING A WAVE FORM ANALYZER

5. FUNDING NUMBERS
AMCMS: 611.02.H611.1

6. AUTHOR(S)
D. Eric Leighton and Ronald T. Abbott

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Benét Laboratories, AMSTA-AR-CCB-O
Watervliet, NY 12189-4050

8. PERFORMING ORGANIZATION REPORT NUMBER
ARCCB-TR-95001

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Close Combat Armaments Center
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
A technique for monitoring the change in compliance of a standard three-point bend specimen during fatigue cycling has been developed. This method allows for accurate measurement of the load-line displacement changes that occur as a crack grows from the notch. The significance of this technique is that it allows accurate determination of crack growth behavior throughout the life cycle of the specimen when a clip gage is impractical or impossible to use.

14. SUBJECT TERMS
Three-Point Bend Specimen, Load-Line Displacement, Crack Growth Behavior, Wave Form Analyzer, Fatigue, Crack-Mouth Opening Displacement

15. NUMBER OF PAGES
10

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

TABLE OF CONTENTS

Tables

List of Illustrations

INTRODUCTION

When fatigue tests are performed with three-point bend specimens, crack-mouth opening displacement is the preferred method to monitor compliance changes of the specimen as the crack grows. Often, however, crack-mouth opening displacement is difficult or impossible to monitor due to notch geometry, such as a wide semi-circular notch. Therefore, to establish the compliance changes under these conditions, another method of monitoring is required. Under load control testing, as a crack begins to grow, the test specimen becomes more compliant requiring greater piston displacement in order to maintain a constant load level. Some difficulties exist with monitoring load-line displacement, including interference from fixture compliance and brinelling (which occurs when the loading pins plastically deform the specimen locally). When monitoring load-line displacement, the brinelling effect causes the piston to deviate from its mean position leading the investigator to erroneously believe that a crack has begun to extend further into the remaining ligament. This type of behavior is also commonly labeled piston float and is a major reason why crack-mouth opening displacement is monitored instead of load-line displacement in fatigue and fracture toughness testing.

This report describes a monitoring technique that effectively eliminates the effect of piston float and allows simple, consistent monitoring of crack growth behavior when fatigue testing or precracking three-point bend specimens. This method is not as accurate as using a clip gage to monitor crack-mouth opening displacement, but it does provide a simple, alternative method when clip gages are difficult or impossible to use.

EXPERIMENTAL METHODS

The technique for monitoring crack growth behavior in this report was developed while cycling three-point bend specimens that contained a 6.35-mm semi-circular notch, as shown in Figure 1. The 84 specimens were cycled at an R-ratio of 0.1 with P_{max} values of 28.7 and 48.3 kN. The material investigated was ASTM A723 steel and the specimens had three different notch surface treatments: shot peened, harperized (which produces a compressive surface stress by plastically deforming a hole or notch using an offset cam), and as-machined.

As shown in Figure 1, the 6.35-mm semi-circular notch in the beam specimens combined with the surface treatments being investigated made it difficult and inadvisable to affix knife edges onto the specimens. Also shown in Figure 1 is a schematic representation of the servo-hydraulic piston motion during fatigue cycling of three-point bend specimens. Since standard servo-hydraulic testing systems, such as the Instron 1332 used in this investigation, are calibrated for tension testing, a downward piston motion is considered positive (since this downward motion would put a tensile specimen in tension), and an upward piston motion is considered negative. By examining the change between the maximum and minimum piston position, Y_{max} and Y_{min}, the investigator could approximate the amount of crack growth during fatigue cycling if the effects of brinelling were reduced or eliminated. To quantify the effects of notch surface treatment, the bend specimens were to be cycled until the change in load-line displacement during the test increased by 10 percent. By examining the number of cycles required to achieve this displacement change, a consistent measure of the notch surface treatment was expected. To determine how consistent this test method was, the specimens were heat tinted at 600°F in air for

one hour and the corresponding 'tinted zone' (fatigue crack length) measured at five locations across the crack front.

EXPERIMENTAL RESULTS

Simple Load-Line Displacement Monitoring

Initially, the specimens in this investigation were cycled in load-control, while the change in piston position was recorded at 1000-cycle intervals. This difference between maximum and minimum piston position is the load-line displacement change and was expected to be an indicator of the extent of fatigue crack growth. After the first 1000 cycles, the difference between the maximum and minimum piston position was recorded and multiplied by 110 percent. This allowed the technician to set a limit switch on the test machines' computer controller to the precise piston stroke position required to obtain a 10 percent increase in displacement change due to crack growth. Since the notch used in this investigation was extremely blunt, 6.35-mm radius, macro-scale crack growth was not expected for several thousand cycles. However, the maximum piston position Y_{max}, or the lowest point to which the piston travels, was slowly rising during the cycling process. At the same time, the minimum piston position Y_{min}, or the highest point to which the piston travels, was also rising. This behavior is commonly referred to as piston float and was assumed to be caused by a combination of the machine warming up and the loading pins plastically deforming into the specimen (the brinelling effect). It was hoped that this behavior would fade as the cycling continued and become negligible after 2000 to 3000 cycles. However, as shown in Figure 2 this effect did not fade, and in fact it became worse as the cycling progressed.

The important point to be made from Figure 2 is the fact that even though the maximum and minimum piston positions are moving, the change between them, Δ, is remaining constant. Thus, no macro-scale crack growth occurs until Δ increases. As mentioned earlier, however, a limit switch had been set to stop the fatigue cycling once 110 percent of the *initial* displacement change, Δ_{init}, had occurred. This limit stroke level, Y_{lim}, is shown in Figure 2 and indicates the minimum position of the piston, which corresponds to the maximum crack-mouth opening displacement when the machine will automatically shut itself off. After ten specimens were tested by this method, the fatigue cracks were measured. Since the test machine was automatically shutting itself off at precisely 110 percent of the original displacement change, the measured fatigue cracks were expected to be approximately equal in length. Table 1, however, shows the range of fatigue crack lengths obtained along with the mean and standard deviation associated with the specimens using the criterion of 110 percent of the original displacement change. Notice also that the mean increase in displacement change (Δ increase (%)) was 14.5 percent--well above the target of 10 percent. This is due to the lack of control the test operator has over adjusting the Y_{lim} to compensate for piston float.

Table 1. Δ Increase (%) and Crack Length Data For Ten Three-Point Fatigue Specimens Tested Using the Load-Line Limiting Method

Load-Line Monitoring		
Specimen	Δ Increase (%)	Crack Length (mm)
1	16.44	10.6
2	15.07	10.5
3	2.74	9.6
4	4.11	9.7
5	29.82	11.4
6	47.71	12.3
7	8.72	10.1
8	0.46	9.4
9	13.7	10.7
10	6.39	10.2
Mean	**14.52**	**10.5**
Std. Dev.	**14.47**	**0.9**

Span/Mean Stroke Position Monitoring

The wave form analyzer, which is typically used in place of an oscilloscope, digitizes the feedback signals from the test machines' controller and allows the user to obtain many different types of information from a specific test being performed. Another benefit that the wave form analyzer has over an add-on signal analyzer like the oscilloscope is that it allows limiting control over the piston actuator. This means that it can be programmed to stop a test when a certain limiting criterion is satisfied. One criterion is the span/mean level. The span is actually the amplitude of the sinusoidal wave form used when performing a standard fatigue test, or in other terms, the difference between maximum and minimum displacement. The mean level is the stroke level around which the piston is cycling. Since the span only changes when the difference between maximum and minimum displacement changes, it does not matter that the pins are plastically deforming into the specimen. The span will only change when the compliance of the specimen changes, i.e., when a crack begins to grow. The mean level, however, does change and this is an exact indication of how much the piston 'floats' during cycling. Figure 3 is a plot of mean level versus cycles using the same data as in Figure 2. Comparing Figure 3 with Figure 4, which is a plot of piston span versus cycles, it is easy to see that the mean level of the piston has no effect on the span of the piston. Therefore, the exact increase in displacement change that is required for testing can be set.

To examine the accuracy of this method, ten more specimens were fatigue cycled--this time to a target Δ increase of 14 percent in order to attempt to match the crack lengths of the ten specimens listed in Table 1. Table 2 shows the improved accuracy of this method, which produces equal crack lengths and allows the operator to automatically stop the test when the desired increase in displacement change is reached. Table 2 shows that by using the span level feedback as the limit switch, with a target Δ increase of 14 percent, the standard deviation is only 1.2 percent, which is significantly less than the 14 percent standard deviation attained by limiting the test based on monitoring the load-line displacement.

Table 2. Δ Increase (%) and Crack Length Data for Ten Three-Point Bend Fatigue Specimens Tested Using the More Accurate Span Limiting Method

Span Level Monitoring		
Specimen	Δ Increase (%)	Crack Length (mm)
11	15.9	10.5
12	13.6	10.3
13	13.1	10.3
14	12.7	10.3
15	15.2	10.3
16	12.2	10.1
17	13.4	10.1
18	14.03	10.6
19	14.7	10.4
20	14.75	11.1
Mean	**13.96**	**10.4**
Std. Dev.	**1.17**	**0.3**

SUMMARY

A simple technique for monitoring the change in compliance of a standard three-point bend specimen during fatigue testing has been developed. By monitoring the span of the piston stroke, the test operator can automatically stop any fatigue test at a prescribed increase in compliance. Unlike monitoring the load-line displacement directly, this method eliminates the effect of brinelling and any other type of piston float. Current applications include fatigue testing specimens with large notches and/or special surface treatments that make it impractical to monitor crack-mouth opening displacement with a clip gage. Other applications may be in monitoring the fatigue precracking of fracture toughness specimens. Once the operator knows the displacement change required to produce a certain length crack in the specimen, the wave form analyzer could be set to shut the machine off at precisely the correct moment. This would save time and dramatically increase the accuracy of the precrack length.

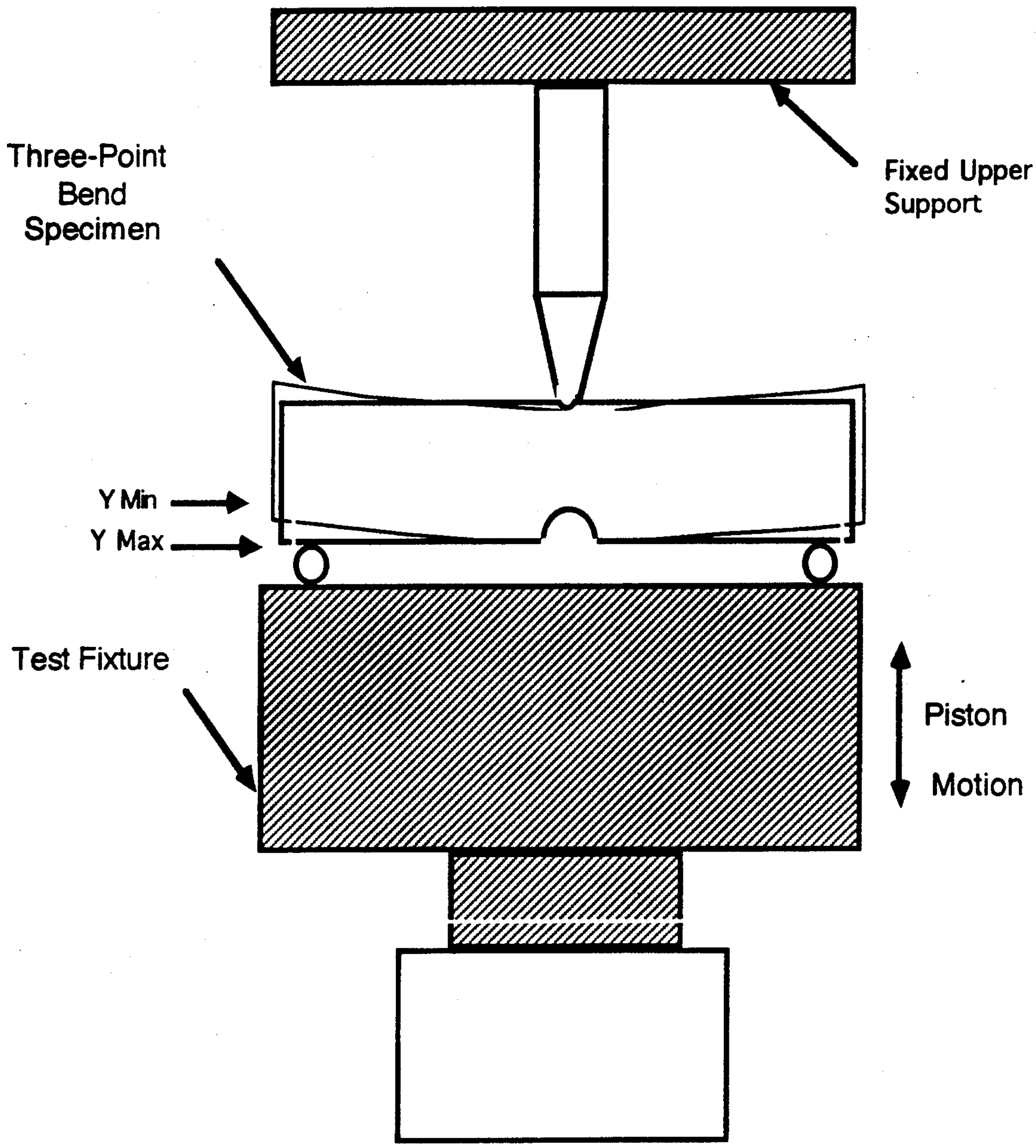

Figure 1. Schematic illustration of the test apparatus showing the bend specimen and the hydraulic piston motion with the corresponding maximum and minimum stroke positions.

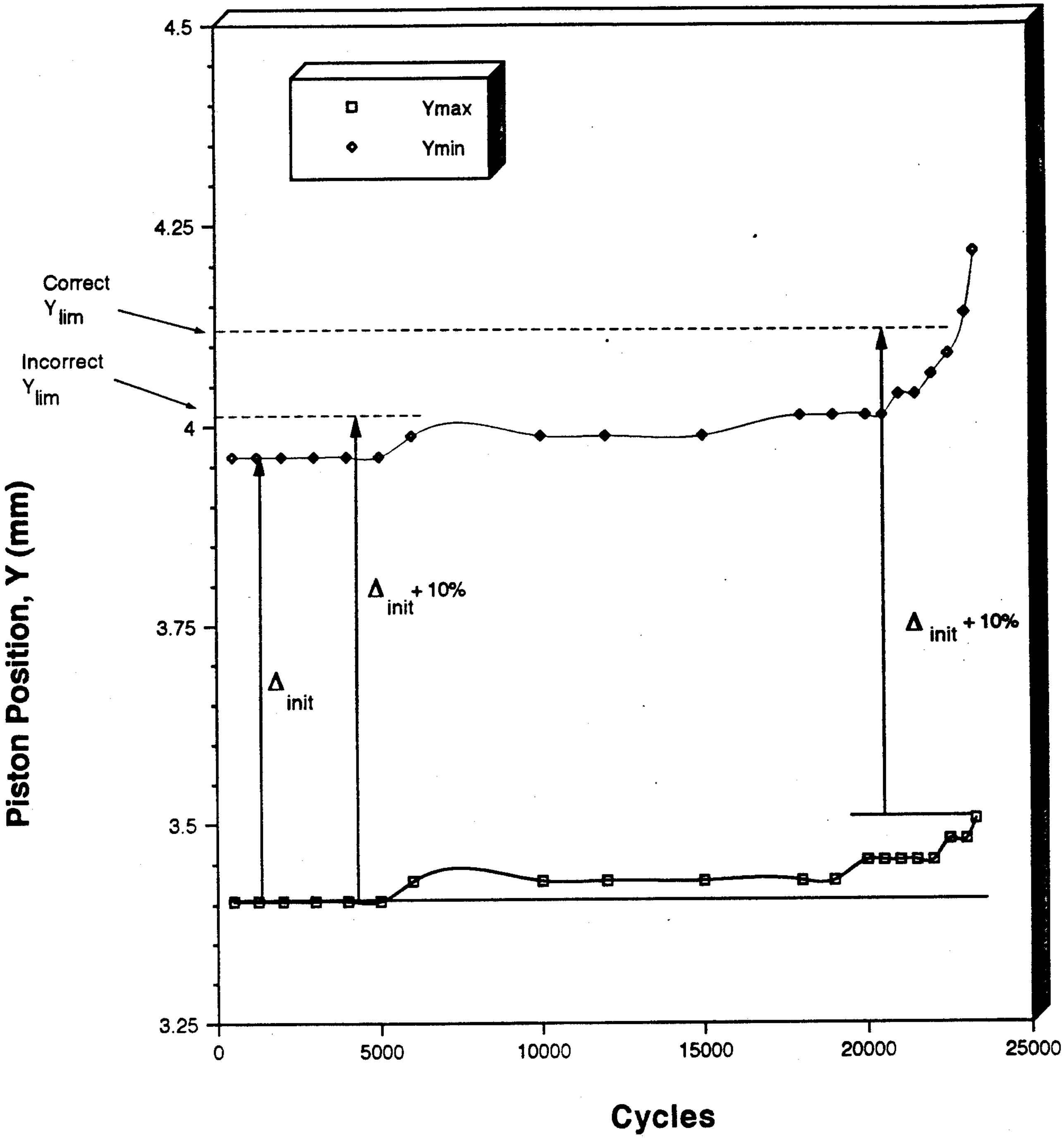

Figure 2. The change in maximum and minimum piston position during fatigue cycling. Also shown are the correct and incorrect limit set points that control the pump shut-off on the servo-hydraulic test machine.

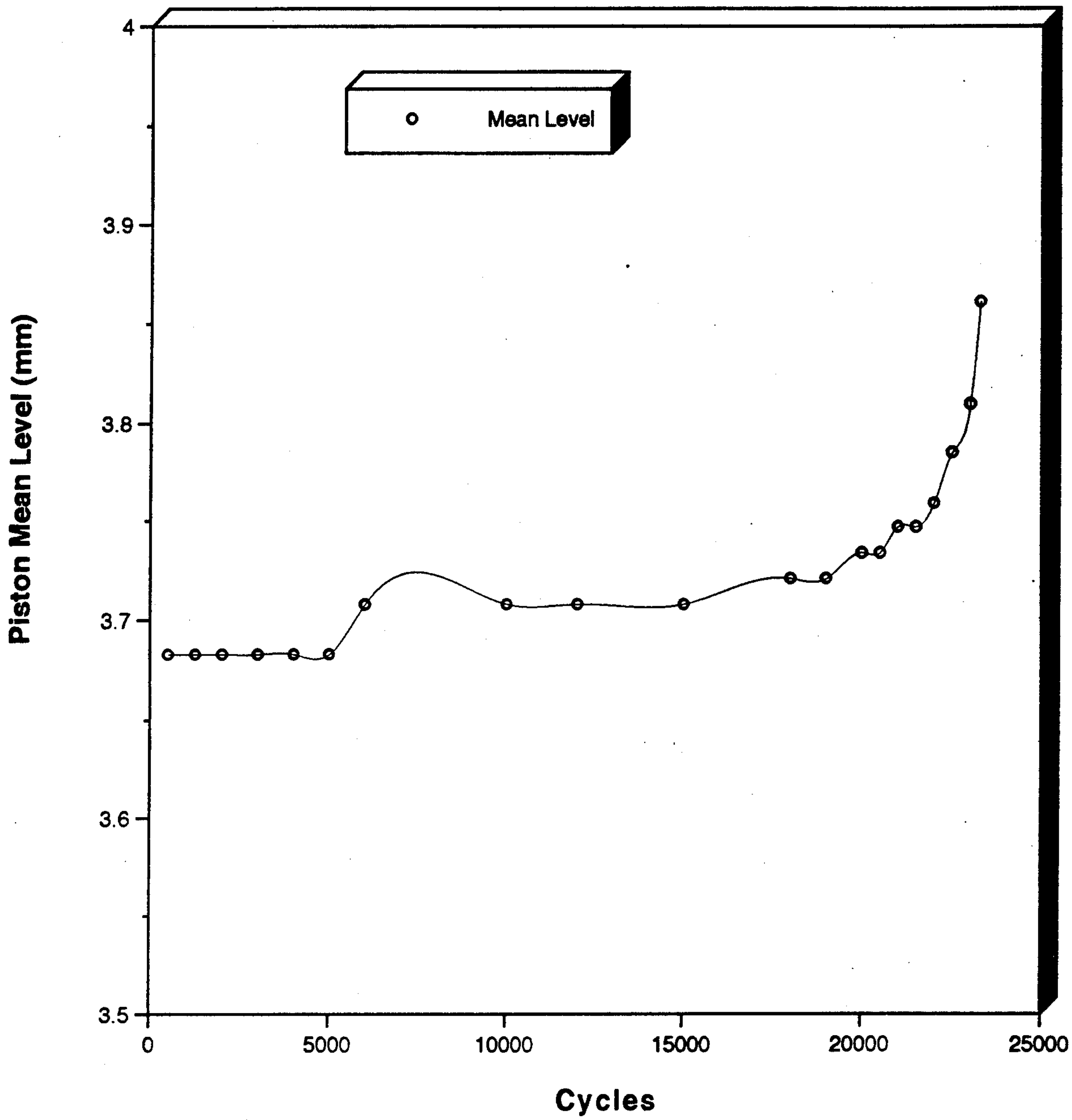

Figure 3. The change in piston mean level as a crack grows in a three-point bend specimen. (Note: Same data as Figure 2.)

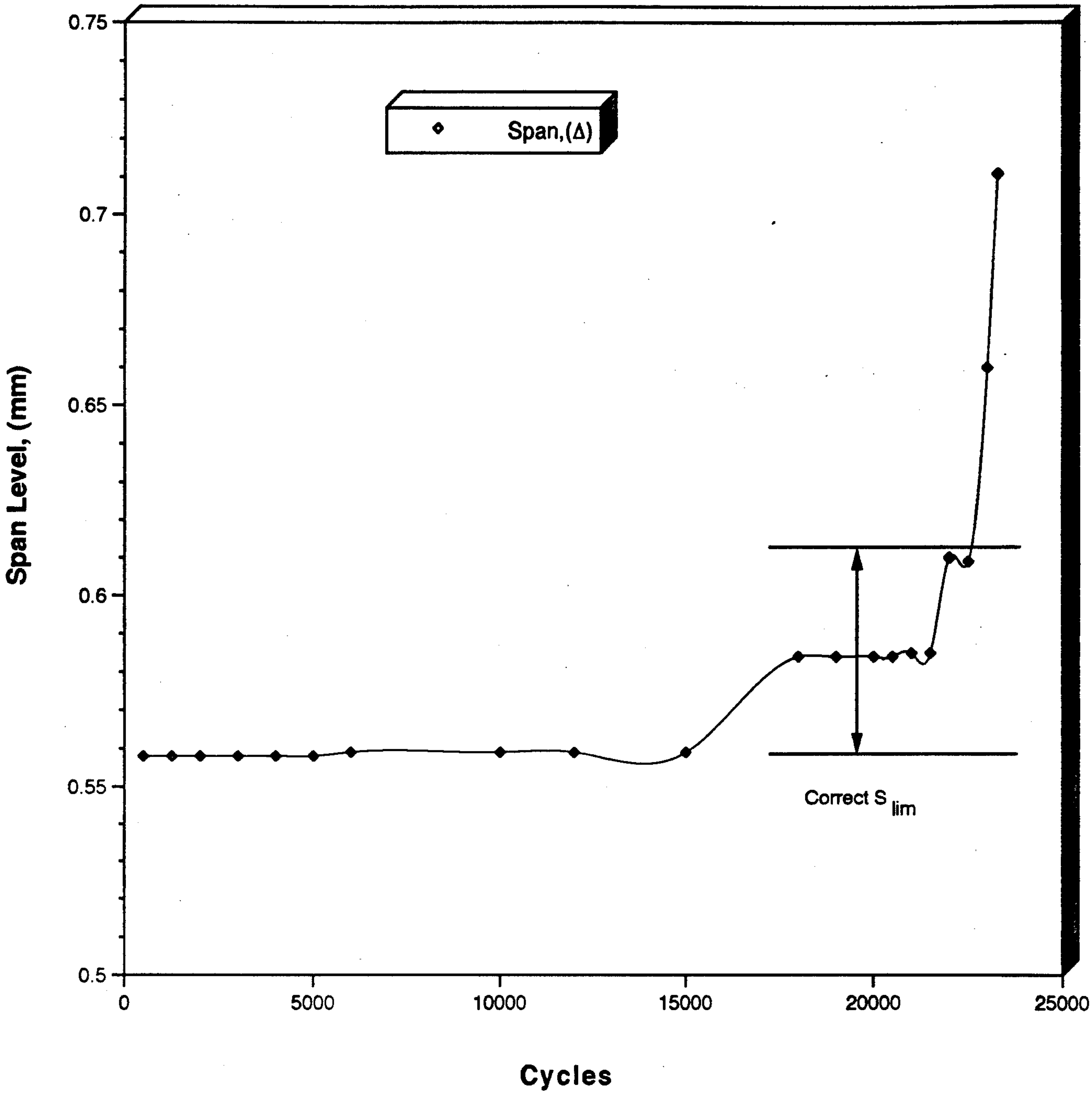

Figure 4. The change in the piston span, which is actually Δ, as a crack grows in a three-point bend specimen. Also shown is the span limit, S_{lim}, which stops the fatigue test exactly at Δ + 10 percent. (Note: Same data as Figure 2.)

TECHNICAL REPORT INTERNAL DISTRIBUTION LIST

	NO. OF COPIES
CHIEF, DEVELOPMENT ENGINEERING DIVISION	
ATTN: AMSTA-AR-CCB-DA	1
-DB	1
-DC	1
-DD	1
-DE	1
CHIEF, ENGINEERING DIVISION	
ATTN: AMSTA-AR-CCB-E	1
-EA	1
-EB	1
-EC	
CHIEF, TECHNOLOGY DIVISION	
ATTN: AMSTA-AR-CCB-T	2
-TA	1
-TB	1
-TC	1
TECHNICAL LIBRARY	
ATTN: AMSTA-AR-CCB-O	5
TECHNICAL PUBLICATIONS & EDITING SECTION	
ATTN: AMSTA-AR-CCB-O	3
OPERATIONS DIRECTORATE	
ATTN: SMCWV-ODP-P	1
DIRECTOR, PROCUREMENT & CONTRACTING DIRECTORATE	
ATTN: SMCWV-PP	1
DIRECTOR, PRODUCT ASSURANCE & TEST DIRECTORATE	
ATTN: SMCWV-QA	1

NOTE: PLEASE NOTIFY DIRECTOR, BENÉT LABORATORIES, ATTN: AMSTA-AR-CCB-O OF ADDRESS CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

	NO. OF COPIES
ASST SEC OF THE ARMY RESEARCH AND DEVELOPMENT ATTN: DEPT FOR SCI AND TECH THE PENTAGON WASHINGTON, D.C. 20310-0103	1
ADMINISTRATOR DEFENSE TECHNICAL INFO CENTER ATTN: DTIC-OCP (ACQUISITION GROUP) BLDG. 5, CAMERON STATION ALEXANDRIA, VA 22304-6145	12
COMMANDER U.S. ARMY ARDEC ATTN: SMCAR-AEE	1
SMCAR-AES, BLDG. 321	1
SMCAR-AET-O, BLDG. 351N	1
SMCAR-FSA	1
SMCAR-FSM-E	1
SMCAR-FSS-D, BLDG. 94	1
SMCAR-IMI-I, (STINFO) BLDG. 59 PICATINNY ARSENAL, NJ 07806-5000	2
DIRECTOR U.S. ARMY RESEARCH LABORATORY ATTN: AMSRL-DD-T, BLDG. 305 ABERDEEN PROVING GROUND, MD 21005-5066	1
DIRECTOR U.S. ARMY RESEARCH LABORATORY ATTN: AMSRL-WT-PD (DR. B. BURNS) ABERDEEN PROVING GROUND, MD 21005-5066	1
DIRECTOR U.S. MATERIEL SYSTEMS ANALYSIS ACTV ATTN: AMXSY-MP ABERDEEN PROVING GROUND, MD 21005-5071	1
COMMANDER ROCK ISLAND ARSENAL ATTN: SMCRI-ENM ROCK ISLAND, IL 61299-5000	1
MIAC/CINDAS PURDUE UNIVERSITY P.O. BOX 2634 WEST LAFAYETTE, IN 47906	1
COMMANDER U.S. ARMY TANK-AUTMV R&D COMMAND ATTN: AMSTA-DDL (TECH LIBRARY) WARREN, MI 48397-5000	1
COMMANDER U.S. MILITARY ACADEMY ATTN: DEPARTMENT OF MECHANICS WEST POINT, NY 10966-1792	1
U.S. ARMY MISSILE COMMAND REDSTONE SCIENTIFIC INFO CENTER ATTN: DOCUMENTS SECTION, BLDG. 4484 REDSTONE ARSENAL, AL 35898-5241	2
COMMANDER U.S. ARMY FOREIGN SCI & TECH CENTER ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1
COMMANDER U.S. ARMY LABCOM MATERIALS TECHNOLOGY LABORATORY ATTN: SLCMT-IML (TECH LIBRARY) WATERTOWN, MA 02172-0001	2
COMMANDER U.S. ARMY LABCOM, ISA ATTN: SLCIS-IM-TL 2800 POWER MILL ROAD ADELPHI, MD 20783-1145	1

NOTE: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH, DEVELOPMENT, AND ENGINEERING CENTER, BENÉT LABORATORIES, CCAC, U.S. ARMY TANK-AUTOMOTIVE AND ARMAMENTS COMMAND, AMSTA-AR-CCB-O, WATERVLIET, NY 12189-4050 OF ADDRESS CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST (CONT'D)

	NO. OF COPIES		NO. OF COPIES
COMMANDER U.S. ARMY RESEARCH OFFICE ATTN: CHIEF, IPO P.O. BOX 12211 RESEARCH TRIANGLE PARK, NC 27709-2211	1	WRIGHT LABORATORY ARMAMENT DIRECTORATE ATTN: WL/MNM EGLIN AFB, FL 32542-6810	1
DIRECTOR U.S. NAVAL RESEARCH LABORATORY ATTN: MATERIALS SCI & TECH DIV CODE 26-27 (DOC LIBRARY) WASHINGTON, D.C. 20375	1 1	WRIGHT LABORATORY ARMAMENT DIRECTORATE ATTN: WL/MNMF EGLIN AFB, FL 32542-6810	1

NOTE: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH, DEVELOPMENT, AND ENGINEERING CENTER, BENÉT LABORATORIES, CCAC, U.S. ARMY TANK-AUTOMOTIVE AND ARMAMENTS COMMAND, AMSTA-AR-CCB-O, WATERVLIET, NY 12189-4050 OF ADDRESS CHANGES.